Overview of HNL sensitivities at protoDUNE

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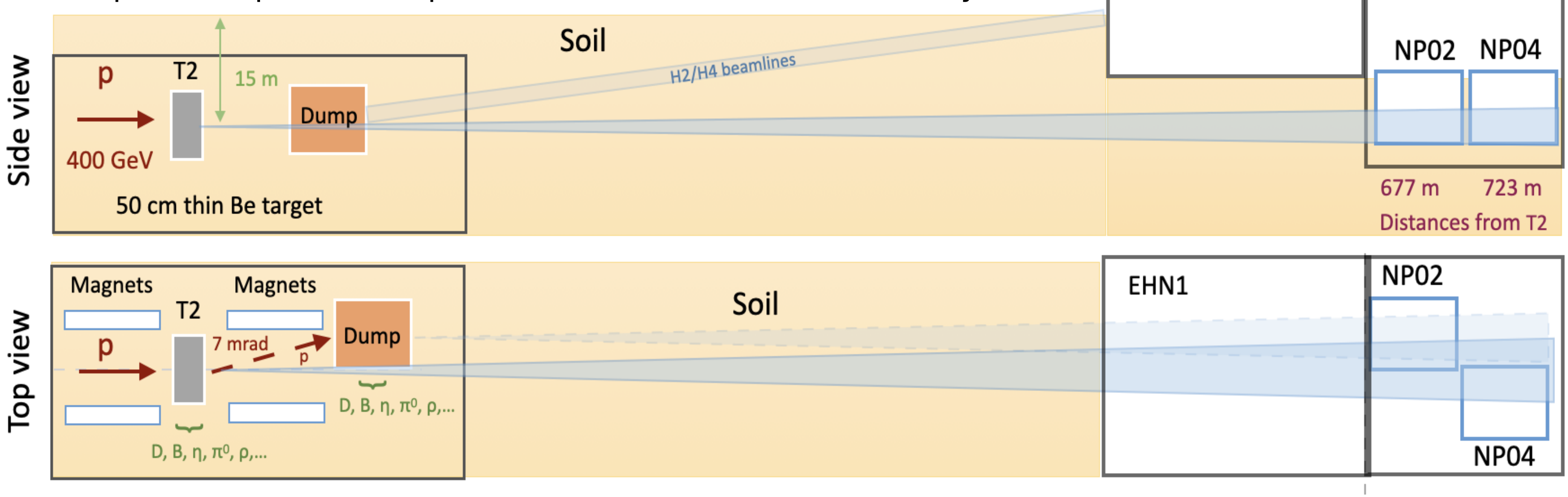
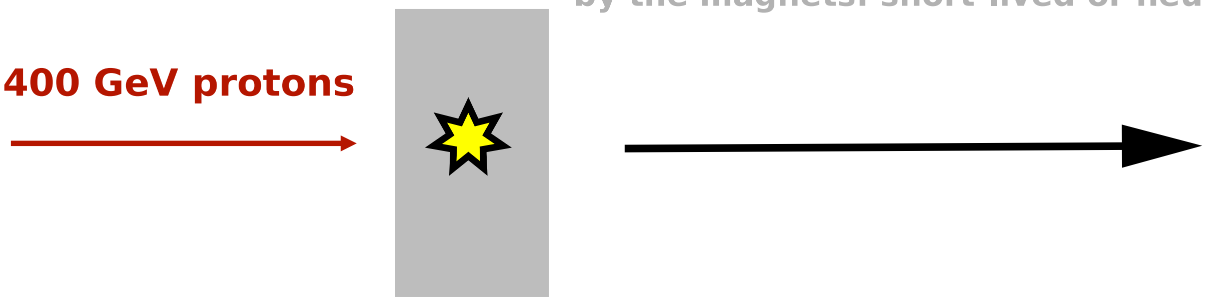
Experimental set-up

Experimental set-up: T2 target

~5-7x10^{12} protons/spill with a spill duration of 4.8 s →3.5x10^{18}PoT/year



We are only interested in mesons not affected by the magnets: short-lived or neutral



Meson production yield Y_M (normalised per PoT)

π^0	η	η'	D	D_s	τ
4.03	0.46	0.05	$4.8 \cdot 10^{-4}$	$1.4 \cdot 10^{-4}$	$7.4 \cdot 10^{-6}$
ρ	ω	ϕ	J/ψ	B	Υ
0.54	0.53	0.019	$4.4 \cdot 10^{-5}$	$1.2 \cdot 10^{-7}$	$2.3 \cdot 10^{-8}$

Distributions obtained from *Pythia*

HNL

HNL: Production

$$\mathrm{L} \supset -\frac{m_W}{v} \bar{N} U^*_{\alpha 4} \gamma^\mu l_{L\alpha} W^+_\mu - \frac{m_Z}{\sqrt{2} v} \bar{N} U^*_{\alpha 4} \gamma^\mu \nu_{L\alpha} Z_\mu$$

We consider the simplified phenomenological benchmarks of one HNL mixing with one SM neutrino of a given flavour

U_{e4} $U_{\mu 4}$ $U_{\tau 4}$

We don't have pions and kaons

Parent	2-body decay	3-body decay
$\pi^+ \to$	$e^+ N_4$	—
	$\mu^+ N_4$	
$K^+ \to$	$e^+ N_4$	$\pi^0 e^+ N_4$
	$\mu^+ N_4$	$\pi^0 \mu^+ N_4$
$\tau^- \to$	$\pi^- N_4$	$e^- \overline{\nu} N_4$
	$\rho^- N_4$	$\mu^- \overline{\nu} N_4$

Parent	2-body decay	3-body decay
$D^+ \to$	$e^+ N_4$	$e^+ \overline{K^0} N_4$
	$\mu^+ N_4$	$\mu^+ \overline{K^0} N_4$
	$\tau^+ N_4$	
$D_s^+ \to$	$e^+ N_4$	—
	$\mu^+ N_4$	
	$\tau^+ N_4$	

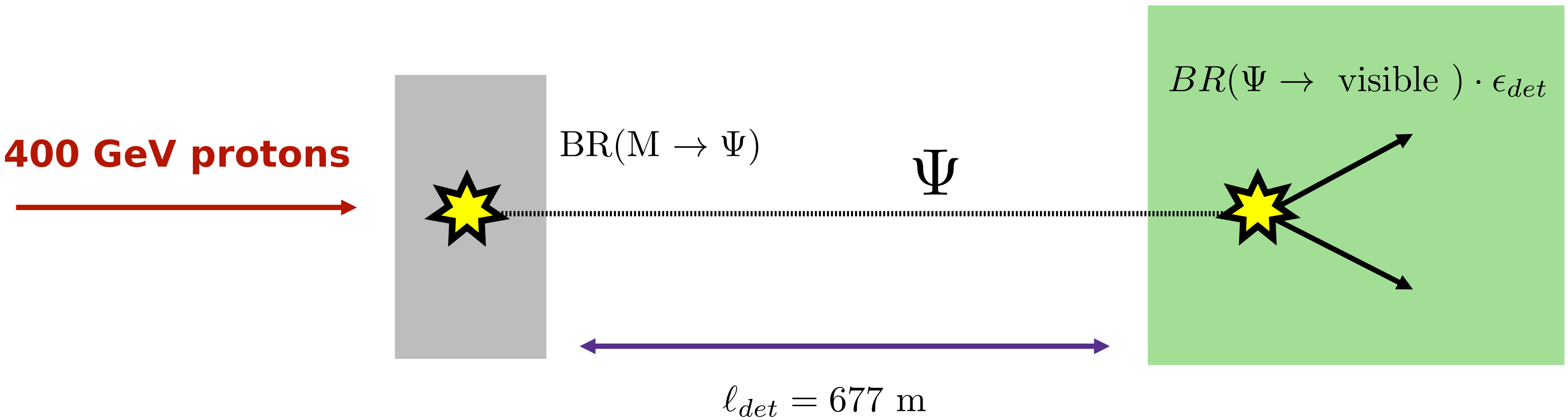
(normalised per PoT)

D	D_s	τ
$4.8 \cdot 10^{-4}$	$1.4 \cdot 10^{-4}$	$7.4 \cdot 10^{-6}$

$Br(D_s^- \to \tau^- \overline{\nu}_\tau) = 5.43\%$

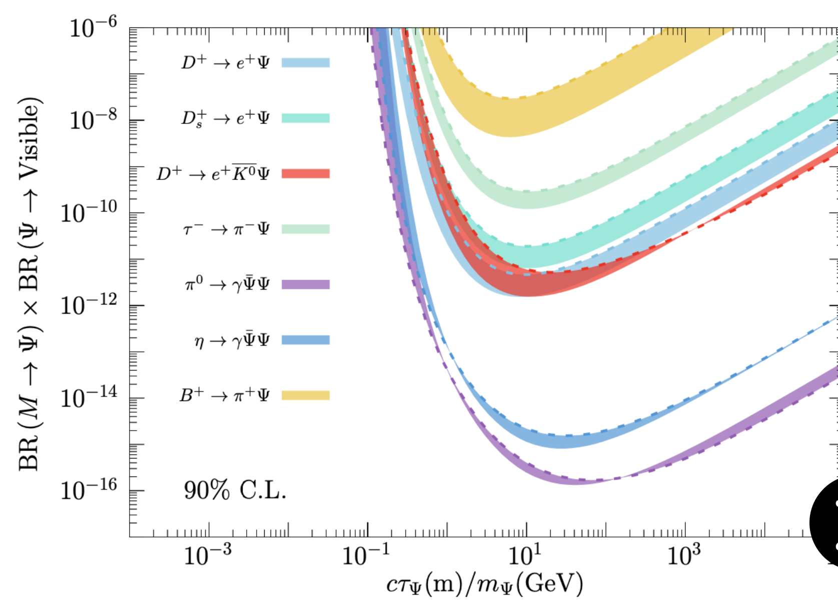
New Physics: Decay in flight inside the detector

Detector(NP02) Liquid Argon TPC



$$\mathrm{N}^{M}_{dec} = N_{\mathrm{PoT}} Y_M \mathrm{BR}(M \to \Psi) \int dS \int dE_\Psi \mathcal{P}\left(c\tau_\Psi/m_\Psi, E_\Psi, \Omega_\Psi\right) \frac{dn^{M\to\Psi}}{dE_\Psi dS}$$

$$\mathrm{N}_{det} = N^{M}_{dec} \cdot BR(\Psi \to \text{ visible }) \cdot \epsilon_{det}$$



$$\mathrm{P} = \mathrm{e}^{\frac{-\ell_{\mathrm{det}}}{L_\Psi}} \left(1 - e^{\frac{-\Delta\ell_{\mathrm{det}}}{L_\Psi}}\right)$$

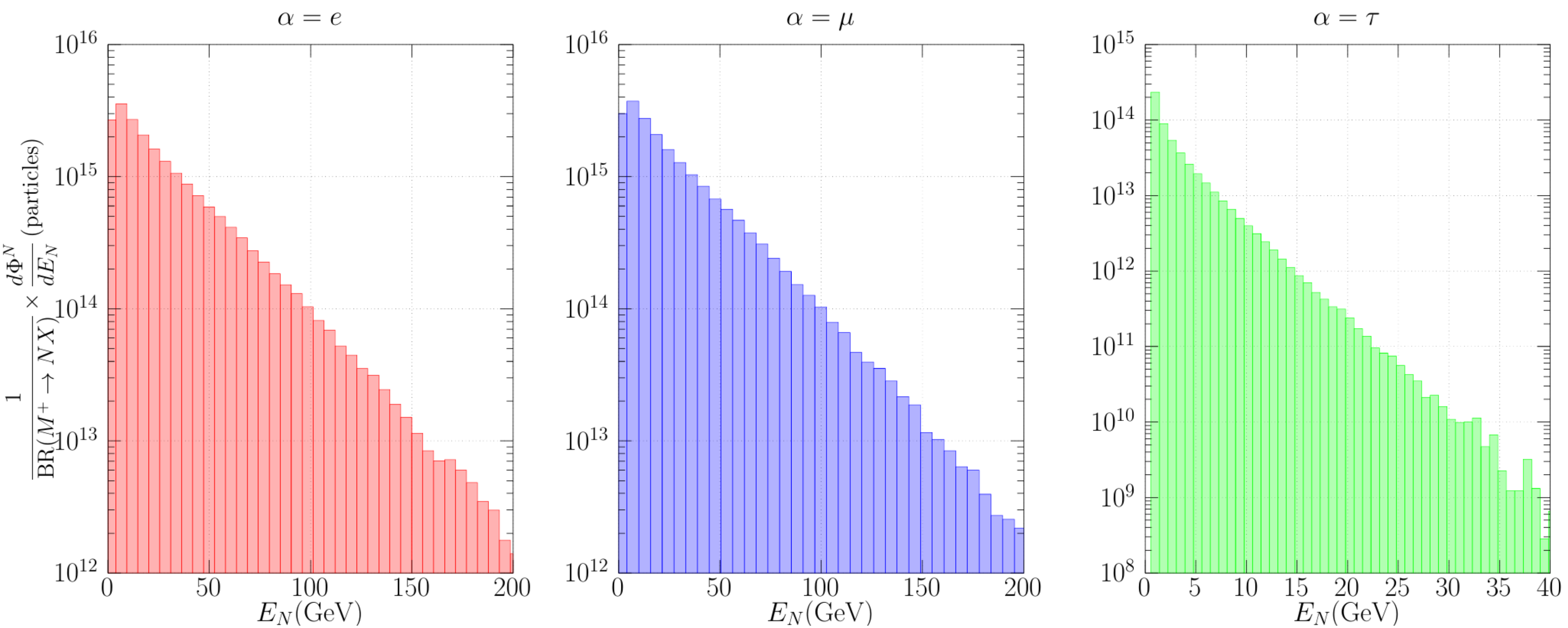
Large couplings

$$e^{-\frac{\ell_{\mathrm{det}}}{L_\Psi}}$$

$$1 - e^{-\frac{\Delta\ell_{\mathrm{det}}}{L_\Psi}} \propto (coupling)^2$$

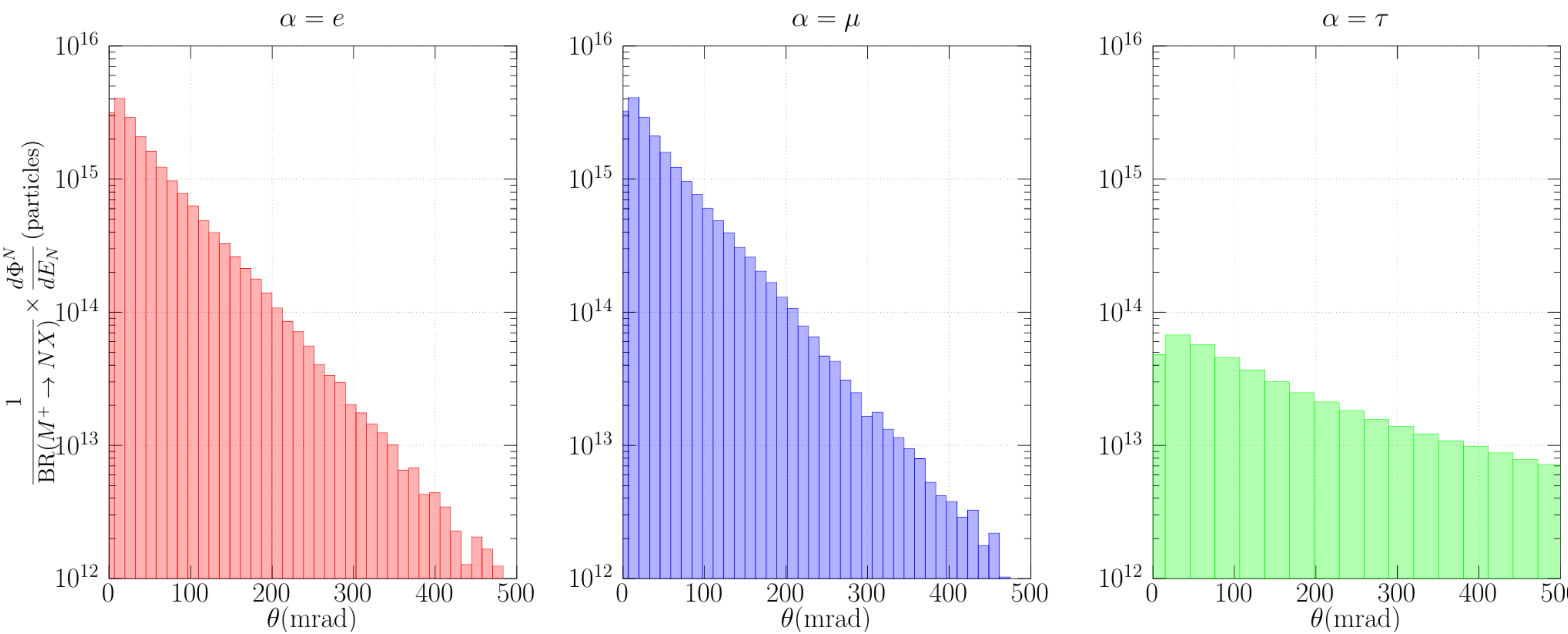
Small couplings

HNL: Fluxes



5 years

HNL: Fluxes

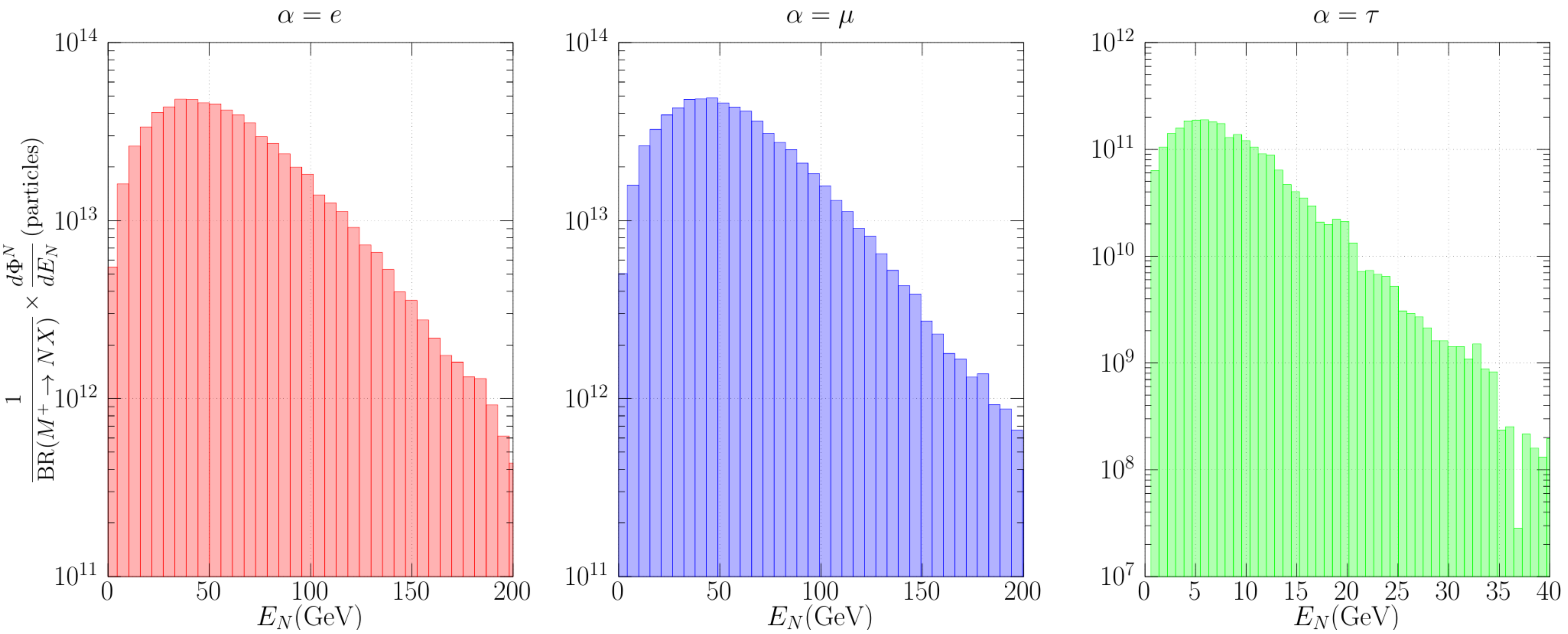


5 years

θ = Angle of the HNL with respect to the forward direction

HNL: Fluxes with detector acceptance

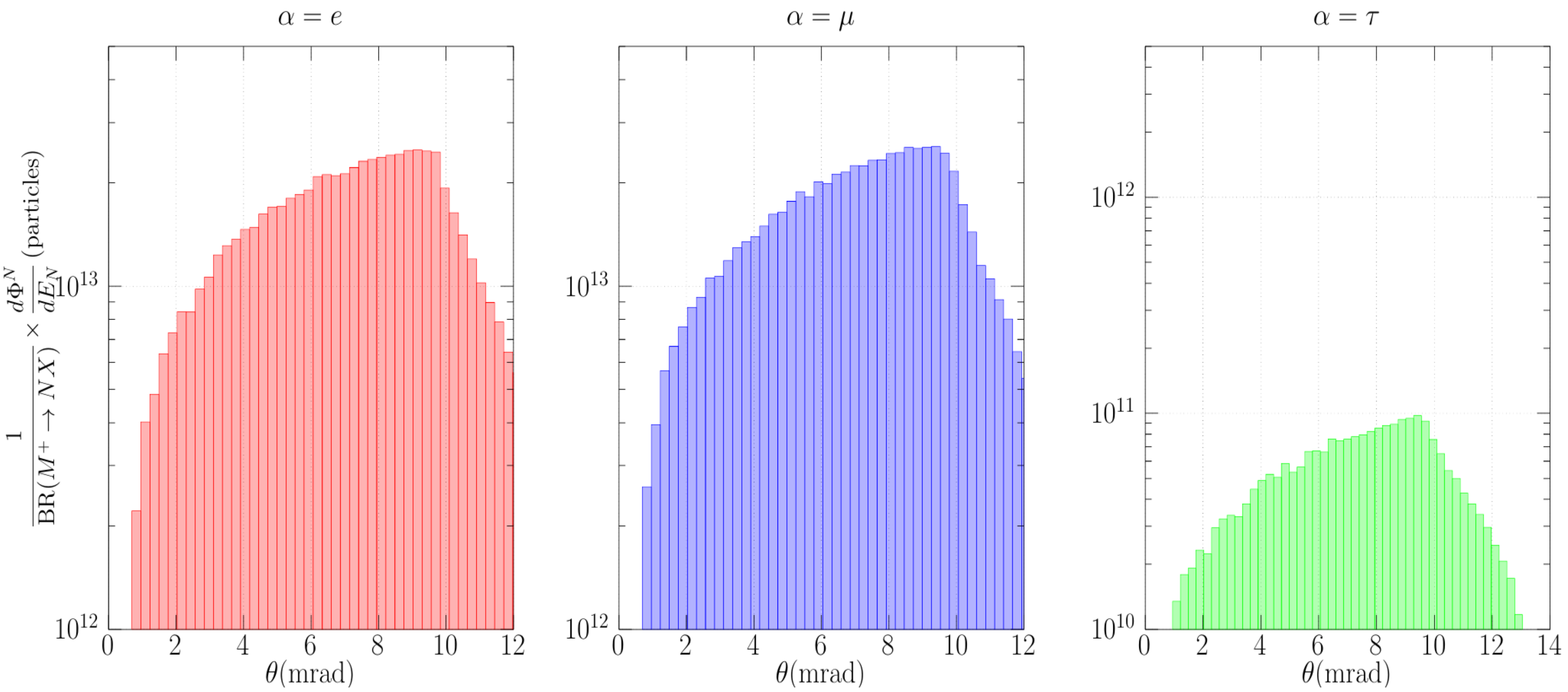
HNL intersecting the detector



5 years

HNL: Fluxes with detector acceptance

HNL intersecting the detector



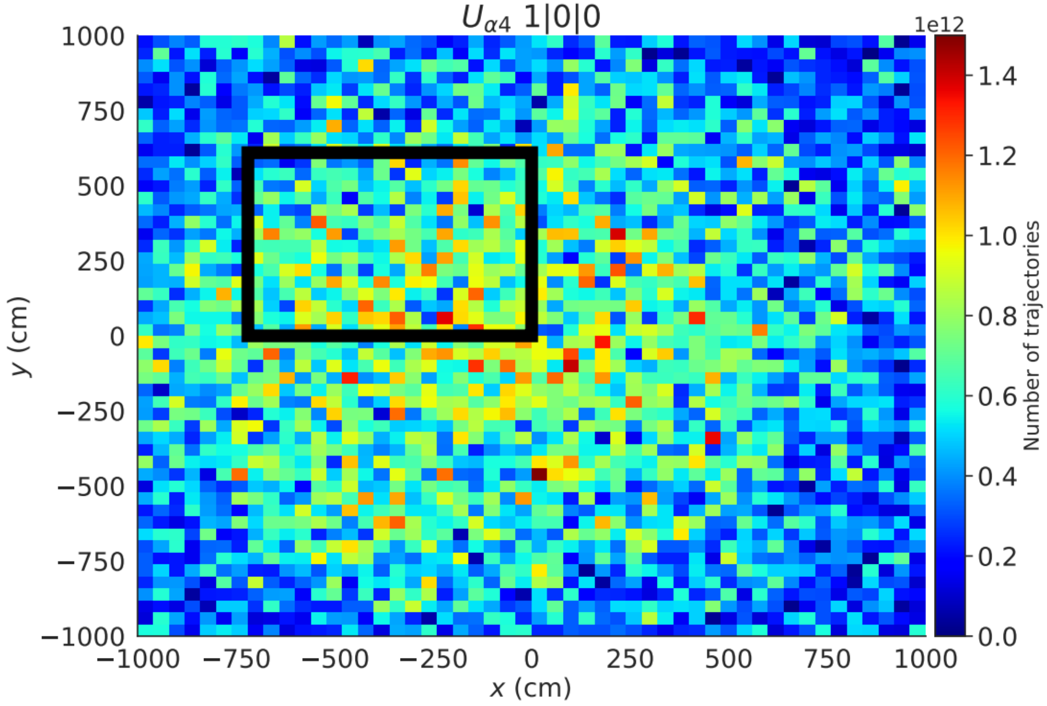
5 years

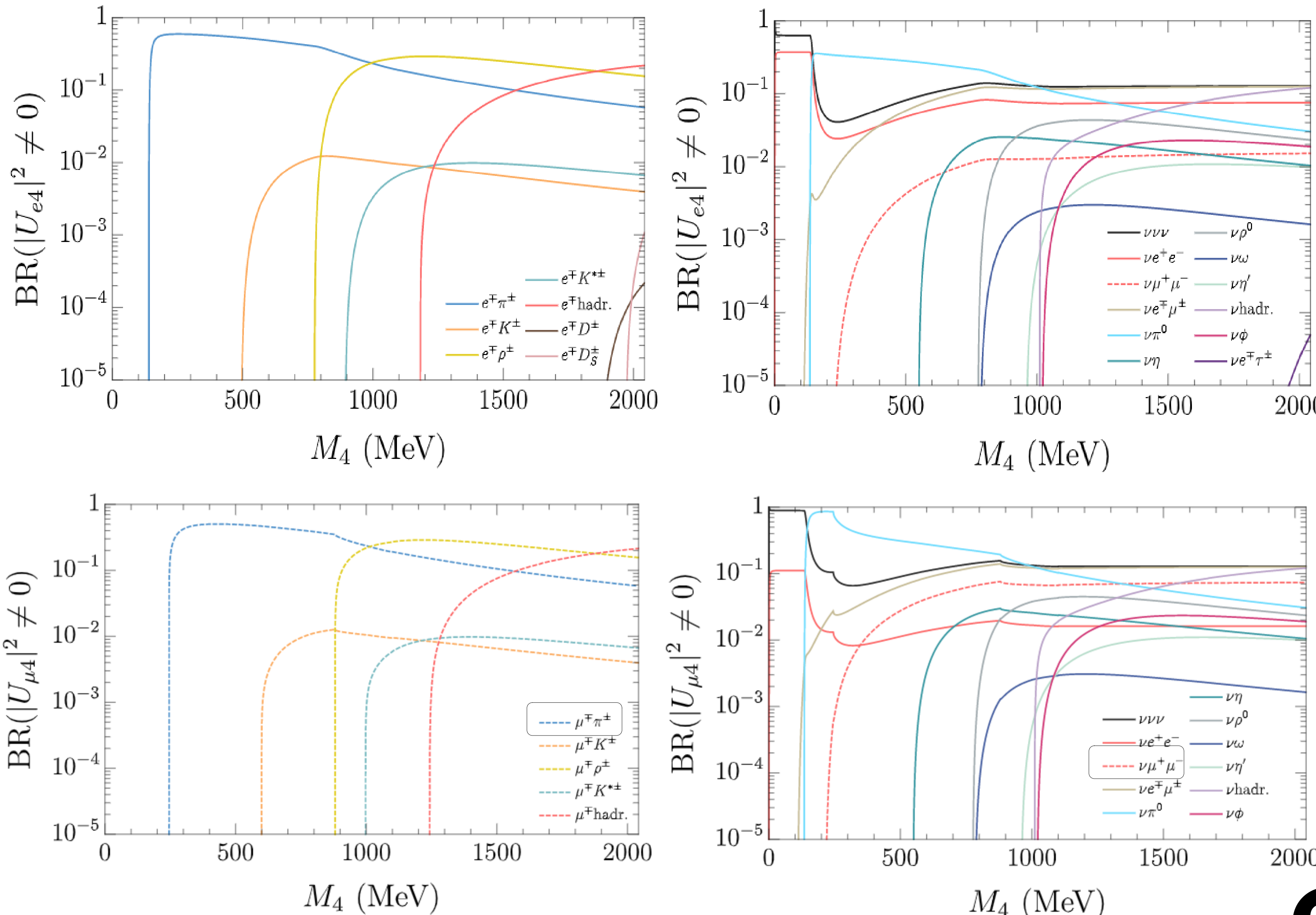
$\theta =$ Angle of the HNL with respect to the forward direction

HNL: Fluxes

- Wide HNL beam
- Small changes in the geometry will not significantly change the results
- Any of the two ProtoDUNE detectors can be used

HNL at z = 677 m

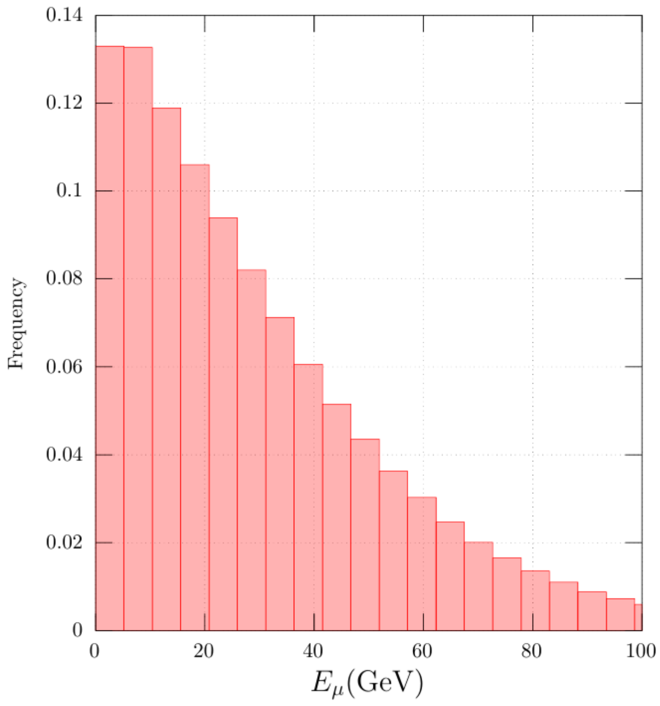


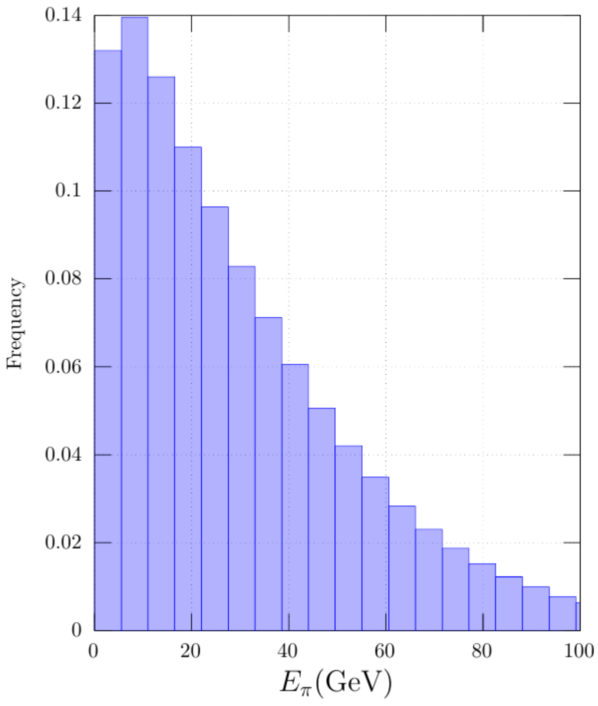


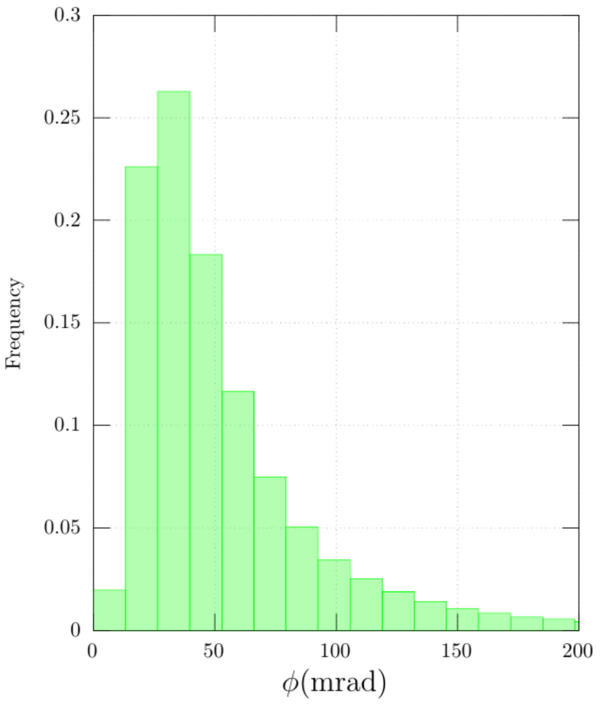
GeV-scale neutrinos: interactions with mesons and DUNE sensitivity. Pilar Coloma, Enrique Fernandez-Martinez, et al.

Signal: two body decay

$$\mathrm{N}_4 \longrightarrow \pi^+\mu^-$$





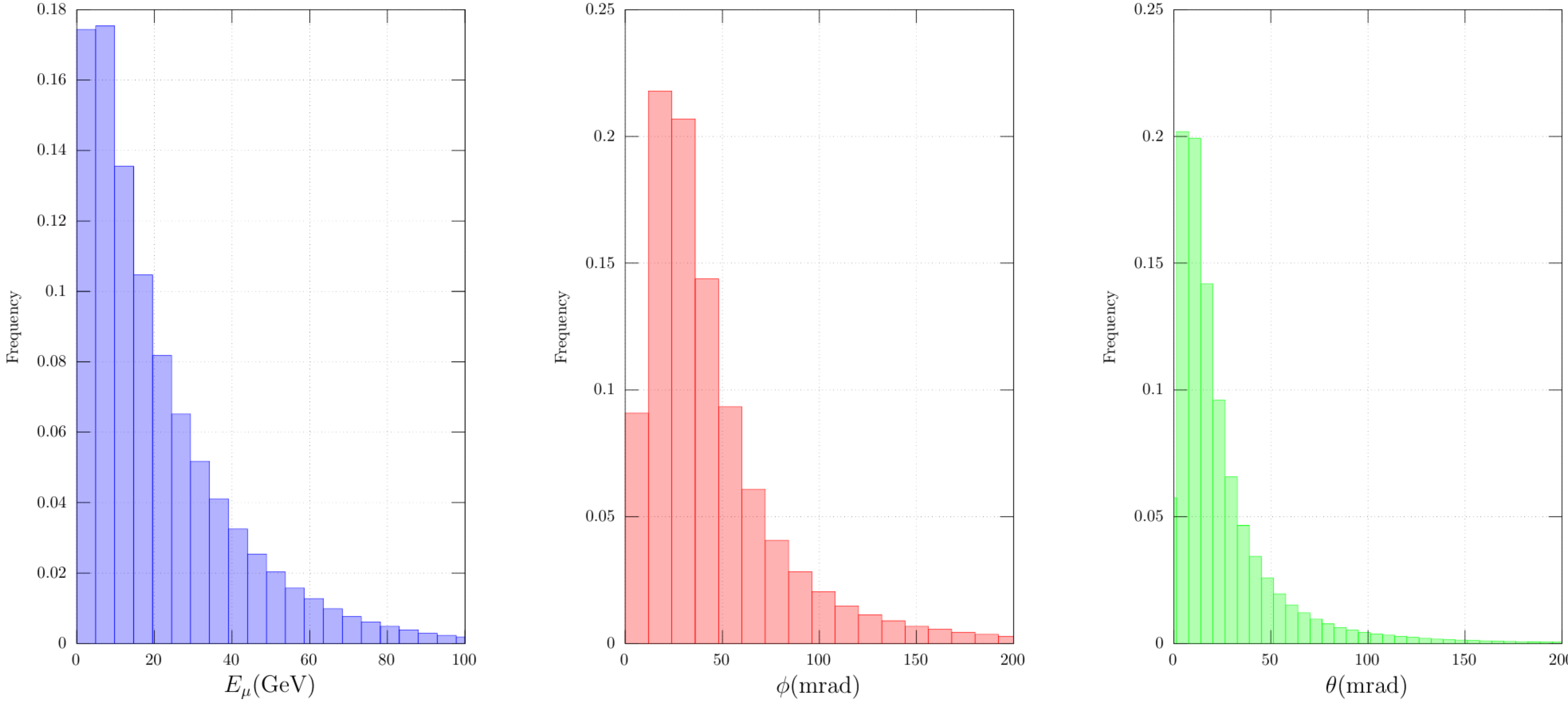


$\phi =$ Opening angle of the muon-pion pair

$\mathrm{m}_N = 1\mathrm{GeV}, U_{\mu 4} = 3 \cdot 10^{-8}$

Signal: three body decay

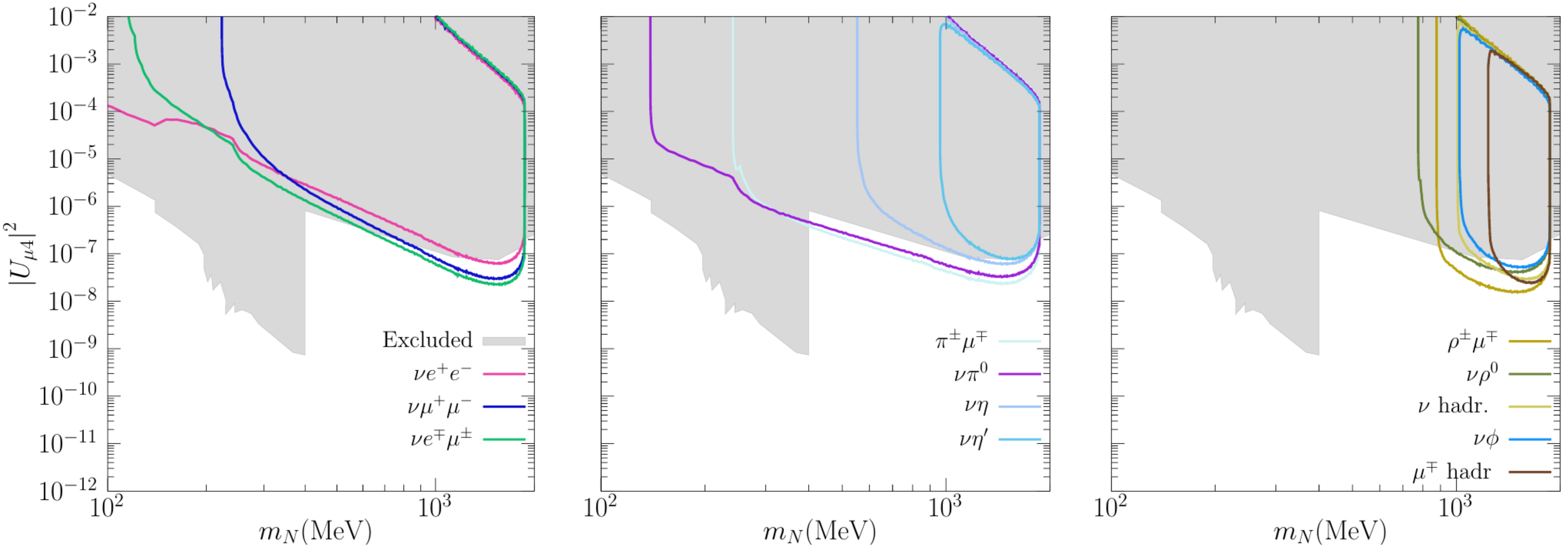
$$N_4 \longrightarrow \nu\mu^+\mu^-$$



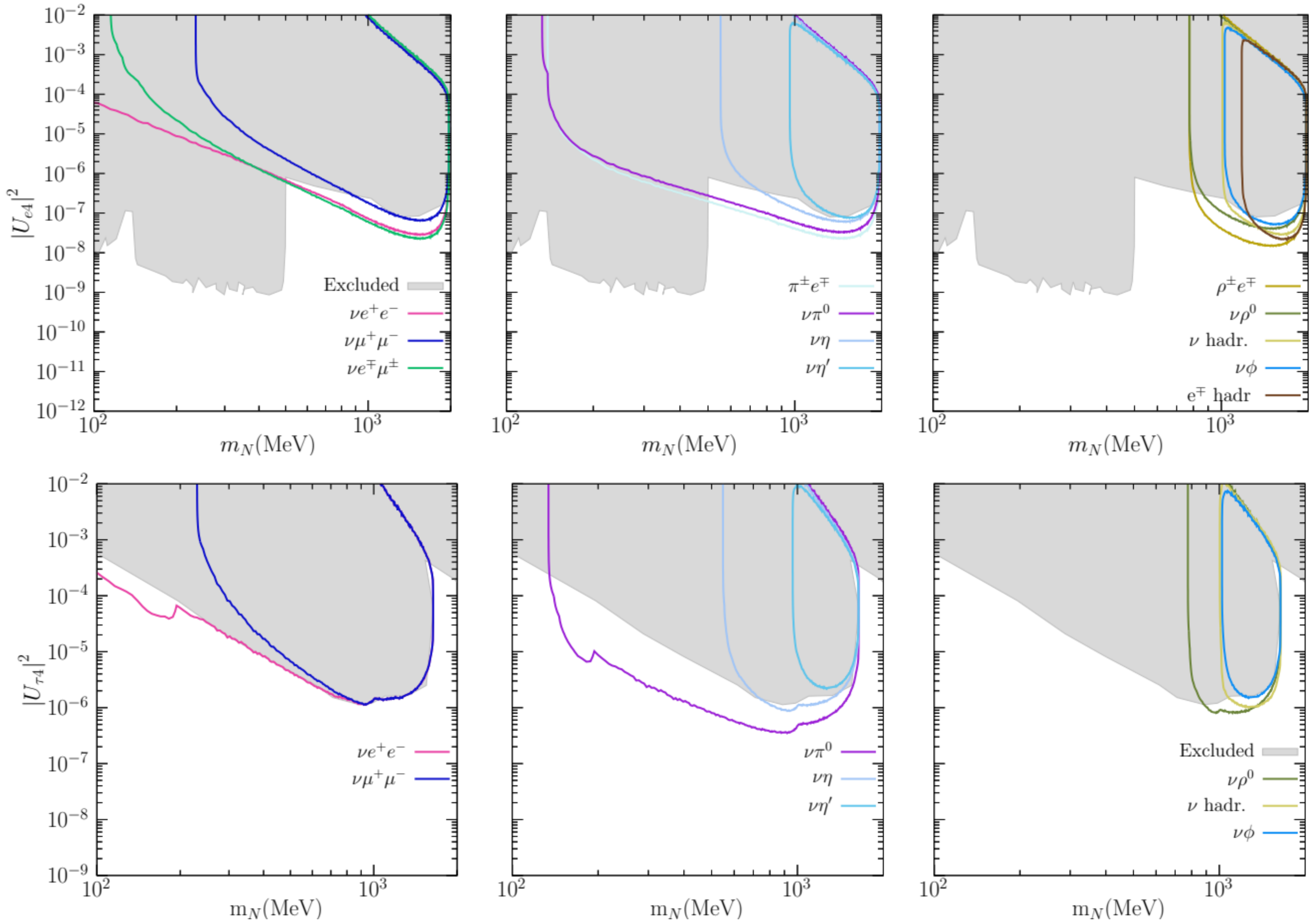
$\theta =$ Angle of the muon pair with respect to the forward direction $\quad m_N = 1\text{GeV}, U_{\mu 4} = 3 \cdot 10^{-8}$

$\phi =$ Opening angle of the muon pair

HNL: Decays into visible channels

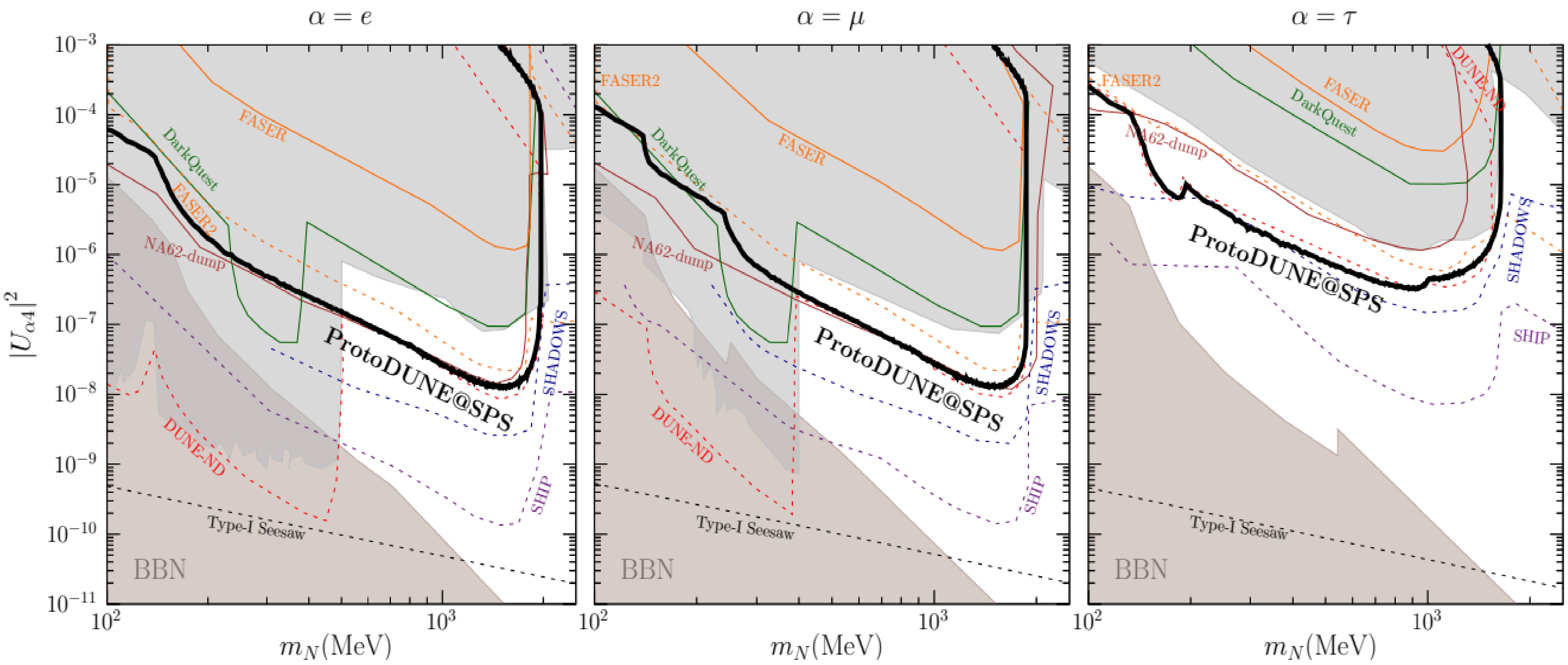


HNL: Decays into visible channels



HNL: Decays into visible channels (combination)

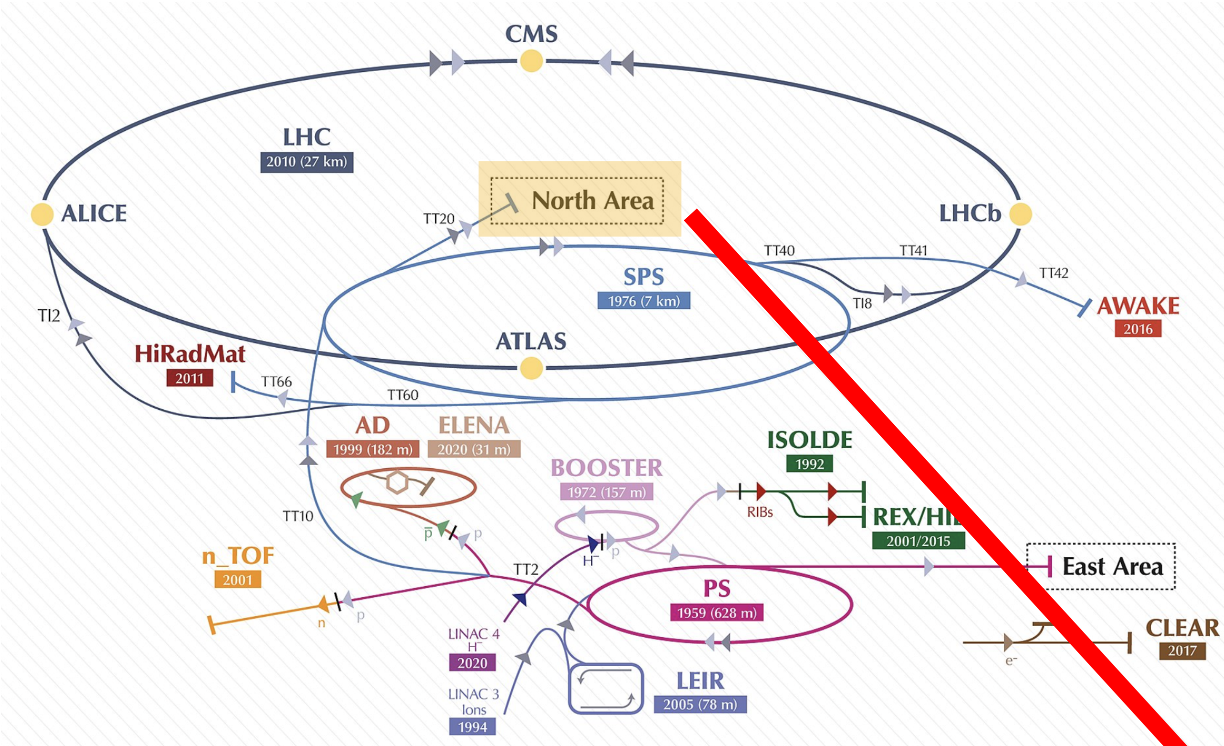
We consider the following channels $N \to \nu ee, \nu\mu\mu, \nu e\mu, e\pi, \mu\pi$ and $\nu\pi^0$

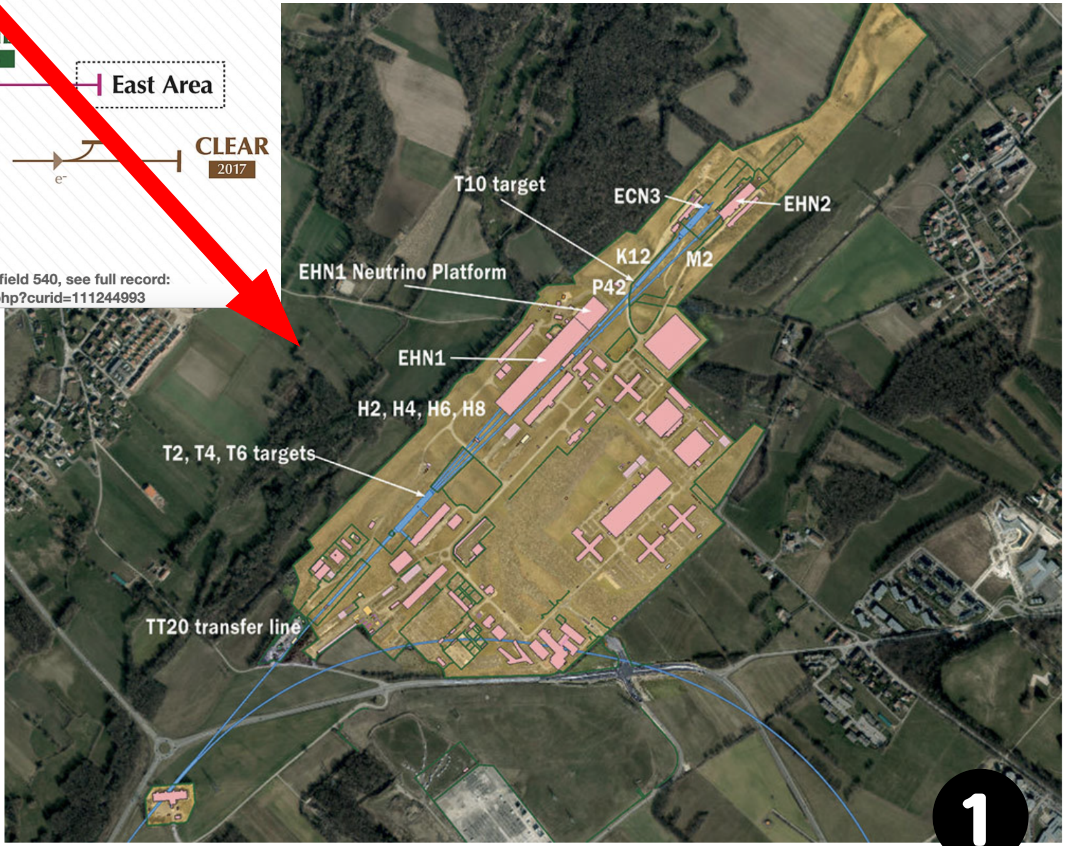


Thank you

Back-up

Experimental set-up: Extracted beam lines





Motivation

Open problems in Particle Physics

Origin of neutrino masses, Baryon asymmetry of the universe and the origin of dark matter

↓ **Provide solutions**

FIPs

↓

They come in many forms

Vector (***Dark Photon)***, Scalar (***Dark Higgs)***, Fermion (***Heavy neutral lepton***), Pseudo-scalar (***Axion***)

Both the interaction strengths with SM particles and the masses of the FIPs range over many orders of magnitude.

Many different types of experiments are needed

When the interaction stregth is sufficiently large and the mass ranges from 10^{-2} GeV to 10 GeV, it can be accessed by accelerator-based experiments

ProtoDUNE run as a Fixed-target experiment

Summary

- The excellent imaging capabilities, the large fiducial volume and the convenient location with respect to the T2 target of the ProtoDUNE detectors make them ideal to search for weakly interacting massive particles in Beyond Standard Model scenarios, such as long lived unstable particles and stable particles. In particular HNL and millicharged particles

Outlook

- A dedicated analysis is required to determine the expected backgrounds and efficiencies for the different detection channels consider.

- The development of a dedicated new trigger is needed for this type of searches

- Other models of new physics can be explored: ALPs, light dark matter, etc.

New Physics

New Physics: Type of searches

New particles produced in meson decays

Long-lived

(HNL, ALPs, dark photon,...)

Decay in flight inside the detector

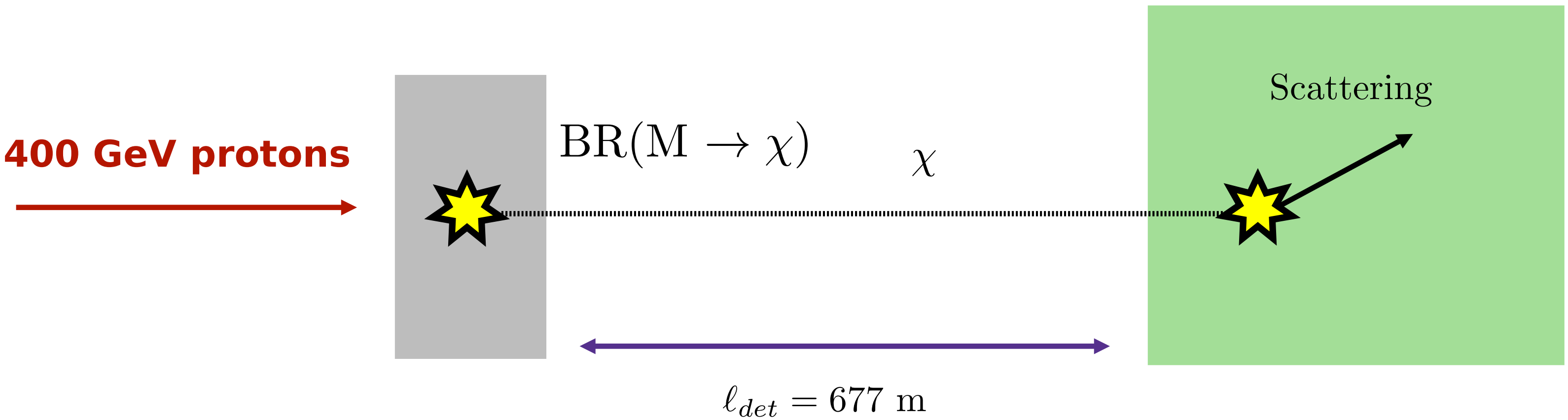
Very long-lived (Stable)

(Milicharged particles,...)

Modify cross sections

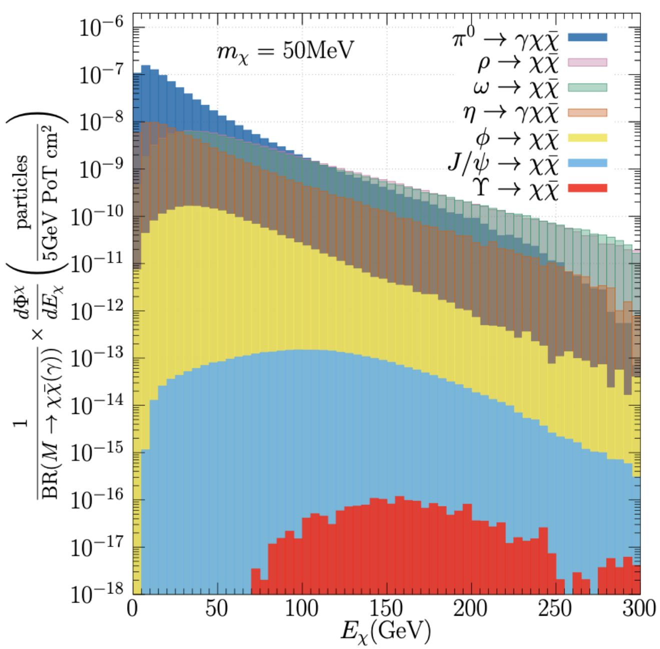
New Physics: stable particles

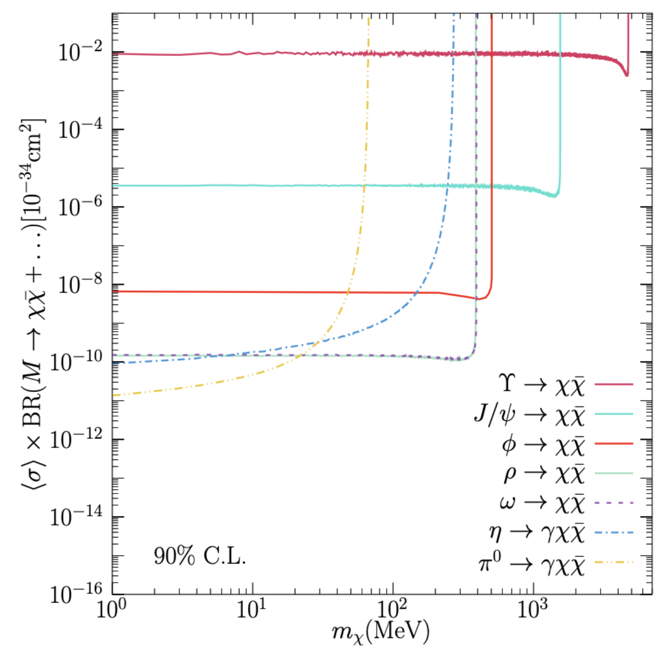
Detector(NP02)
Liquid Argon TPC



$$\langle\sigma\rangle = \frac{1}{\Phi^\chi}\int_0^\infty \int_{T^{\min}}^{T^{\max}} \frac{d\sigma}{dT}\left(E_\chi, \{X\}\right) \frac{d\Phi^\chi}{dE_\chi} dT dE_\chi$$

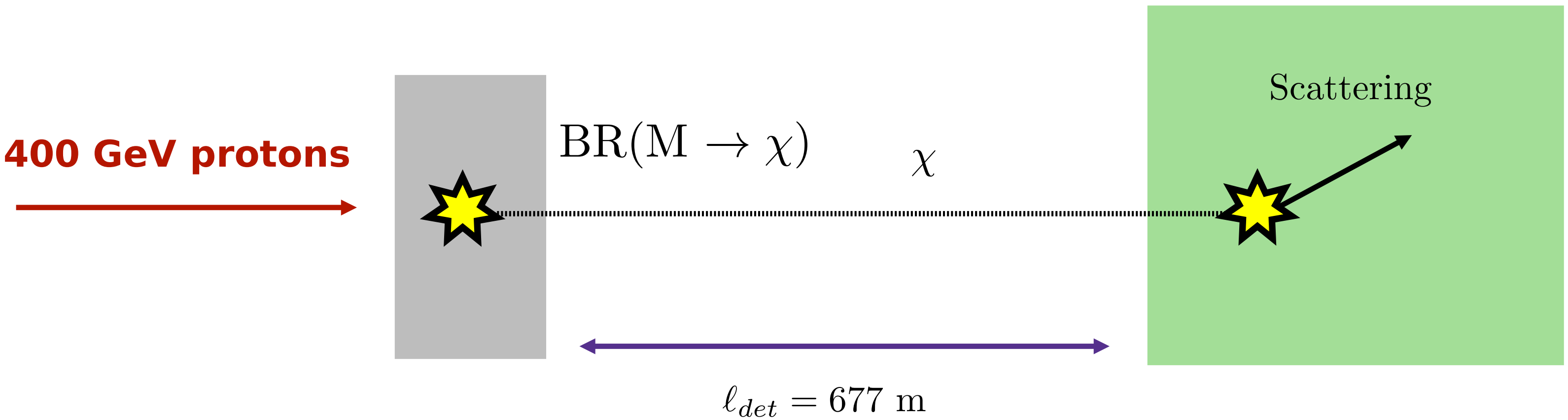
$$\mathrm{N}_{ev} = \epsilon_{\rm det}\, N_{trg} \langle\sigma\rangle \Phi^\chi N_{\rm PoT},$$

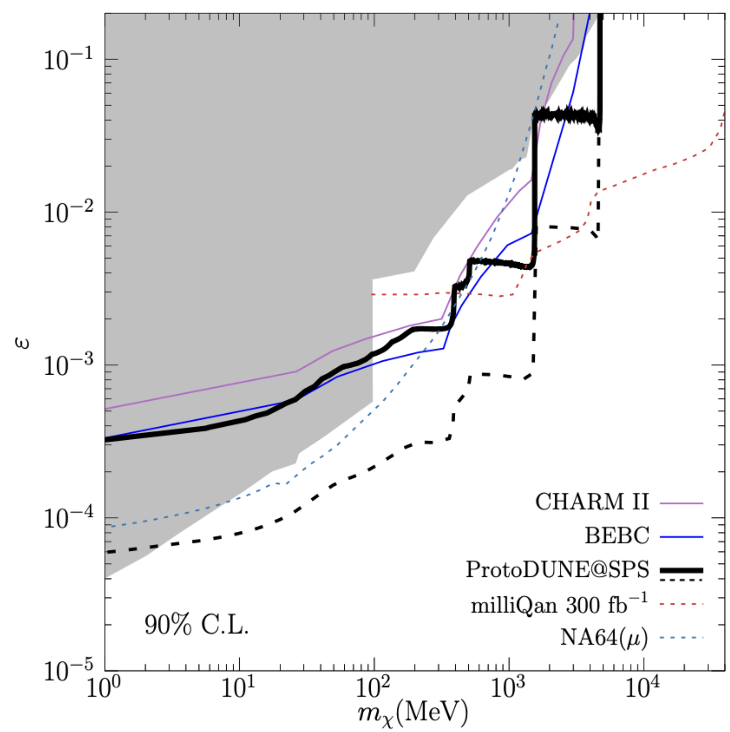




Millicharged particles

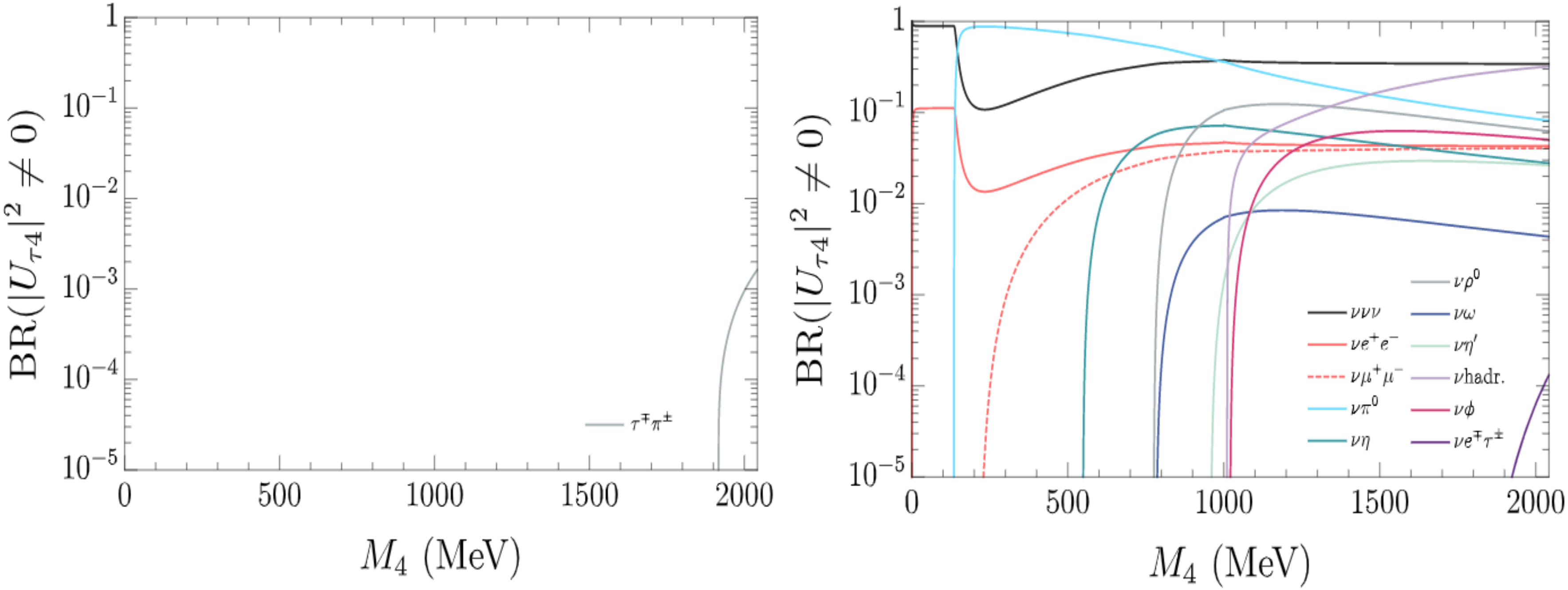
Detector(NP02)
Liquid Argon TPC





$$\mathrm{N}_{ev} = \epsilon_{\mathrm{det}}\, N_{trg} \langle\sigma\rangle \Phi^{\chi} N_{\mathrm{PoT}},$$

$$\sigma \sim \varepsilon^2 \left(\frac{30\mathrm{MeV}}{T_{\min}}\right) 10^{-26}\ \mathrm{cm}^{-2},$$


BR($|U_{\tau 4}|^2 \neq 0$)
M_4 (MeV)
$\tau^\mp\pi^\pm$
$\nu\nu\nu$
νe^+e^-
$\nu\mu^+\mu^-$
$\nu\pi^0$
$\nu\eta$
$\nu\rho^0$
$\nu\omega$
$\nu\eta'$
νhadr.
$\nu\phi$
$\nu e^\mp\tau^\pm$